now compared the arrangement of the *nif K*, *D* and *H* genes in whole filaments of *Anabaena* with that in heterocysts during their differentiation from vegetative cells. While confirming that *nif K* is separated from *nif D/H* in vegetative cells, they show that a gene rearrangement occurs within the heterocyst at a late stage in differentiation. What happens is that the 11-kilobase intervening DNA sequence between *nif D/H* and *nif K* is excised, so that the three genes become clustered and function as a single transcriptional unit, with nitrogenase structural proteins being synthesized, and nitrogenase activity commencing, within the heterocysts. The excised portion remains in the heterocyst as a circular molecule of unknown function.

These findings are of interest not only because they are unique but because they emphasize the usefulness of cyanobacteria for the study of differentiation. The heterocysts of cyanobacteria such as *Anabaena*, show a distinct spatial pattern; between 8 and 10 per cent of the total cells along a filament are heterocysts and new heterocysts develop equidistantly from two existing heterocysts. That is, in some as yet unknown way, existing heterocysts may regulate the spacing pattern of new heterocysts (there is no evidence that nitrogenase is involved in the process). Furthermore, in organisms such as *Nostoc* 7524 there is evidence that with certain external (and no doubt internal) conditions, a cell that normally develops into a heterocyst develops instead into an akinete[12]. The molecular events leading to the cessation of cell division and determining whether a differentiating cell regresses, or further differentiates, and if so into which cell type, is an intriguing area of molecular biology that has relevance not only to nitrogen fixation but to our basic understanding of cellular developmental biology. At a time when the UK Agricultural and Food Research Council is examining N_2-fixation research, the new results with cyanobacteria will, perhaps, emphasize the merits of scientific diversity in this field. □

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Scale-invariant phenomena

Viscous fingers and fractal growth

from L.M. Sander

A RECENT article in Nature by Nittmann, Daccord, and Stanley[1] is a particularly instructive example of the power of basic science to find connections between apparently unrelated natural phenomena. It is an experimental account of the shape of the interface between two fluids with relevance to oil-field technology. The shape is shown to belong to a class that includes the shapes of electrolyte deposits[2,3], metals and dielectric breakdown structures such as lightning[4]. The common feature of the objects is that they are all scale-invariant fractals of the same fractal dimension[5].

The experiment of Nittmann *et al.* deals with the long-known fact that when a relatively non-viscous fluid is forced against a viscous fluid an instability results: 'fingers' of the less viscous fluid intrude into the other. For example, when carbon dioxide is pumped into an oil field, the efficiency of oil recovery is not very large because instead of the oil being pushed uniformly across the field, it is broken up by the branching pattern of the fingers. The usual laboratory realization of the system is a Hele-Shaw cell: water is pumped into a long channel in which oil is trapped between closely-spaced parallel plates. In the essentially two-dimensional region between the plates, fingering is easily seen.

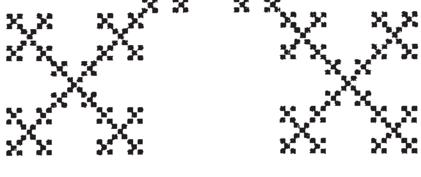
In past experiments, the shape of the fingers has been dominated by the interfacial tension between the two fluids, which tends to favour coarse fingers. Typically, one finger is formed with a width near to that of the cell. But, in an oil field, the region of interest is much bigger than a single finger. To simulate the oil field in their experiments, the essential step of Nittmann *et al.* was to use two fluids whose interfacial tension is essentially zero — water and an aqueous polymer solution that has a slow rate of mixing with water. In addition, the polymer solution has very high effective viscosity. Both these factors favour the formation of small fingers.

It is with respect to the sprawling, many-branched structures formed as the small fingers of water advance into the polymer solution that connections can be made to disparate phenomena. For, as Paterson has pointed out[7], the fundamental instability in this situation is the same as in other systems where diffusion limits growth. Here, fingers grow because it is easier for viscous fluid to flow away from a sharp tip than a flat interface. In dielectric breakdown, the electric field is largest at the end of the breakdown channel, leading to further extension at the point. In electrolyte deposition, new ions more easily find sharp tips than flat areas; the tips thus extend.

For instability dominated growth, the unifying framework is the diffusion-limited aggregation (DLA) model[8]. In this idealization of growth by diffusion, which is used in computer simulations, a particle walks randomly until it finds a nucleation centre, where it sticks. Then another particle is released and walks until it finds either the centre or the other particle and sticks. And so on. The remarkable result of the simulations is that the structures they form are scale-invariant and fractal.

Scale-invariant objects look the 'same' at any magnification. The disorderly structures already mentioned share this property with other natural objects, such as coastlines. The figure gives a simplified example, generated by an obvious rule, which looks the same at a discrete set of magnifications. In order to see what is meant by a fractal, we define D, the fractal dimensionality[5]. Cover the object in the figure with a set of disks of radius r. This takes a certain number of disks, $N(r)$. Now change r and see how N changes. Almost always we find $N(r) = Cr^{-D}$ where C is a constant. For a straight line, $D = 1$ and for a square, $D = 2$; in these cases D corresponds to our usual ideas of dimensionality. But for the illustrated figure, dividing the radius by 3 multiplies N by 5. Thus $D = \log(5)/\log(3)$. An object whose D is not given by its topology is a fractal.

Electrolyte deposits, dielectric breakdown stuctures and DLA clusters all have a measured D of about 1.7 in two dimensions of space. Their fractal properties can be studied using the simple DLA model. The fingers of Nittmann *et al.* have a smaller D, but the authors show that this is probably the effect of the finite width of their channel. All of these structures belong to the same universality class which seems to be that associated with growth far from equilibrium. Another class, corresponding to DLA in three dimensions (with $D = 2.4$), has been seen in electolyte deposition[2]. Still another class appears in



the description of flow through porous materials — 'the percolation problem'.

The experiment of Nittmann *et al.* is also significant in that it gives insight into the minimum requirements of a DLA-like structure. Although DLA seems quite simple, it has defied complete analysis. A major point of contention is whether noise due to the discrete nature of the particles making up the cluster dominates the dynamics. Dielectric breakdown structures have links of more-or-less fixed length and electrolytic deposits are polycrystalline. Experiments on these systems shed no light on the question. But the fluid system of Nittman *et al.* is continuous. Apparently, discreteness is not essential to make a DLA-like fractal. There has been speculation that this would indicate that DLA is an example of chaos. In practical terms it may mean that solidification far from equilibrium, which can also be mapped onto DLA, could give rise to fractals — for example, if a snowflake were allowed to grow very large, it would probably be fractal, too. □

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100 Years Ago

THE following account, we learn from *Science*, of unusual phenomena was received, March 10, at the Hydrographic Office, Washington, from the branch office in San Francisco. The barque *Innerwich*, Capt. Waters, has just arrived at Victoria from Yokohama. At midnight of February 24, in latitude 37° north, longitude 170° 15′ east, the captain was aroused by the mate, and went on deck to find the sky changing to a fiery red. All at once a large mass of fire appeared over the vessel, completely blinding the spectators; and, as it fell into the sea some fifty yards to leeward, it caused a hissing sound, which was heard above the blast, and made the vessel quiver from stem to stern. Hardly had this disappeared when a lowering mass of white foam was seen rapidly approaching the vessel. The barque was struck flat aback; but, before there was time to touch a brace, the sails had filled again, and the roaring white sea had passed ahead. The master declares that the awfulness of the sight was beyond description and considers that the ship had a narrow escape from destruction.

From *Nature* **31** 514, 2 April 1885.

Oceanography

Sonar classification of sea beds

from M.L. Somers

ALTHOUGH side-scan solar is used widely in both scientific and engineering investigations of the sea bed, the task of extracting a numerical classification of sea beds from the backscattered sound has proved intractable. But an experienced human observer who has had access to the results of comparisons between sonographs and physical samples can rapidly make accurate qualitative classifications, so there must be some quality of the backscattering that gives the necessary clues. On page 426 of this issue, Z. Reut, N.G. Pace and M.J.P. Heaton offer a solution to the problem and a method of classification into six sea-bed types — mud, sand, clay, gravel, stones and boulders.

The backscattering of sound from the sea bed is a complicated function of the grazing angle of the sonar signal and the roughness of the sea bed, with further complications thrown in by the acoustic impedance of the sea-bed material: if the ratio of sea bed to water impedance is close to unity (as in the case of mud), then there is appreciable penetration of sound into the sea bed and the possible production of a boundary wave, which can interact with the incident wave, profoundly modifying the backscattering process (see Somers, M.L. and Stubbs, A.R. *IEE Proc.* **131**, Pt F; 1984). To circumvent these problems, Reut *et al.* have concentrated on the rate of fluctuation of the backscattered sound over short periods of time. Their method is based on the observation that the fluctuations generally become more rapid as the ground gets rougher. There are, of course, large differences in total energy, and the peak-to-valley ratios can actually be greater over a soft or smooth sea bed than over a rough one, but the rate of fluctuation is still generally less than if the sea bed is rough.

The method requires fairly careful normalization, for which Reut *et al.* have chosen to use cepstrum analysis, an outline of which is given in their paper. By taking the mean of the power spectrum, all considerations of phase can be ignored, so ensuring that when the inverse transform is taken the result peaks at, or near to, zero time delay. The effect of taking logs before doing the inverse transform is to de-emphasize any d.c. level in the signal, which shows up as a large peak at zero frequency in the power spectrum. The two-power cepstrum integral parameters give a measure of how closely the cepstrum is confined to low time-lag values.

Justification of the method comes both from the foregoing qualitative arguments that can be mustered in its favour and from the fact that it seems to work — 120 sea-bed areas are correctly classified into the six types with the only overlap being between gravel and stone types. A similar result could probably be obtained by applying automatic gain control, removing the mean and taking the auto-correlation function, though this would possibly be computationally less attractive.

It would be interesting to see the method applied to a wider selection of sea-bed echoes, using a number of frequencies instead of the single 48-kHz frequency used by the authors. An application which comes to mind concerns the problem of mapping and assessing fields of manganese nodules in oceans that are several thousand metres deep. This will require low-frequency sound, such as used in the long-range side-scan sonar, GLORIA II. Manganese nodule fields occur very widely in the Abyssal Plain regions of the deep ocean and should be visible on a GLORIA record. If so, it might at least be possible to delineate the boundaries of the fields, and perhaps even to give a measure of nodule abundance.

Side-scan sonar requires oblique incidence for its best visual effect, so that depth/range ratios need to be less than about 0.2. But most systems working from the surface in deep water, or at high frequencies in shallow water, operate at near-vertical incidence and the backscattering process is somewhat different. It will be interesting to see how the classification system of Reut *et al.* performs in such circumstances.

Turning from their concern with problems of propagation and surface reverberation, the underwater-acoustics community is devoting increasing attention to sonar scattering. Many theoretical papers and some reporting measurements or equipment will be given at the International Conference on Scattering Phenomena on 2-3 April at the Admiralty Research Establishment, Portland, UK. Various applications of the analysis of sea-bed backscattering, both civil and military, are being explored. Of the civil applications, many involve the estimation of resources. Manganese nodules have already been mentioned. Gravel provides a second example. Over ten per cent of the gravel used in the United Kingdom is dredged from the sea bed, and a rapid and reliable means of detecting suitable gravel fields would be of considerable value. The accuracy of acoustic logs for ships that measure their speed by observing the Doppler shift of sound backscattered from the sea bed should also be improved by application of the new system of classification. □

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